The CDF Time of Flight Detector

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October 21, 2003 IEEE NSS/MIC PORTLAND, Oregon

Outline

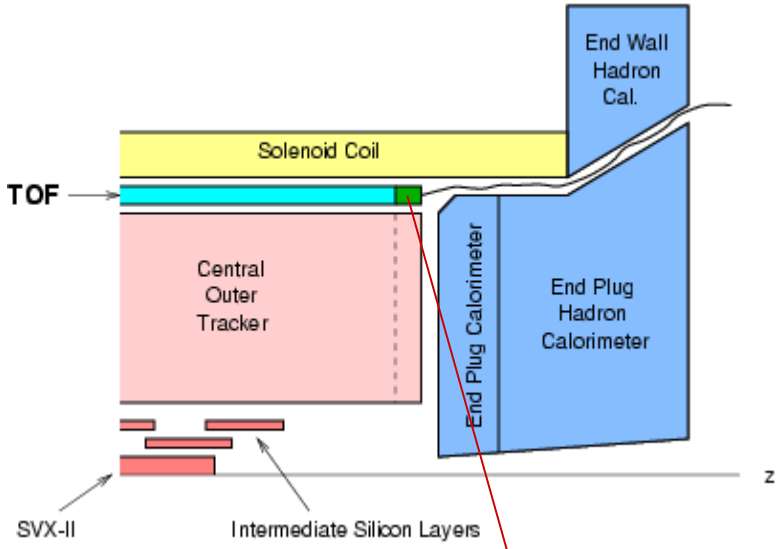
- TOF detector in CDF
- TOF technique
- Calibrations
- t_o calculation
- TOF triggers
- TOF resolution
- Physics with TOF
  - B physics
  - Minimum bias QCD
  - Exotic physics
- Conclusions


CDF

TOF in CDF

Cylinder of 216 scintillator bars at radial distance from beam pipe 1.4 m

- Bicron BC-408
- Att. length 2.5 m
- Fast rise time 0.9 ns
- 4 x 4 x 280 cm



PMT at each end

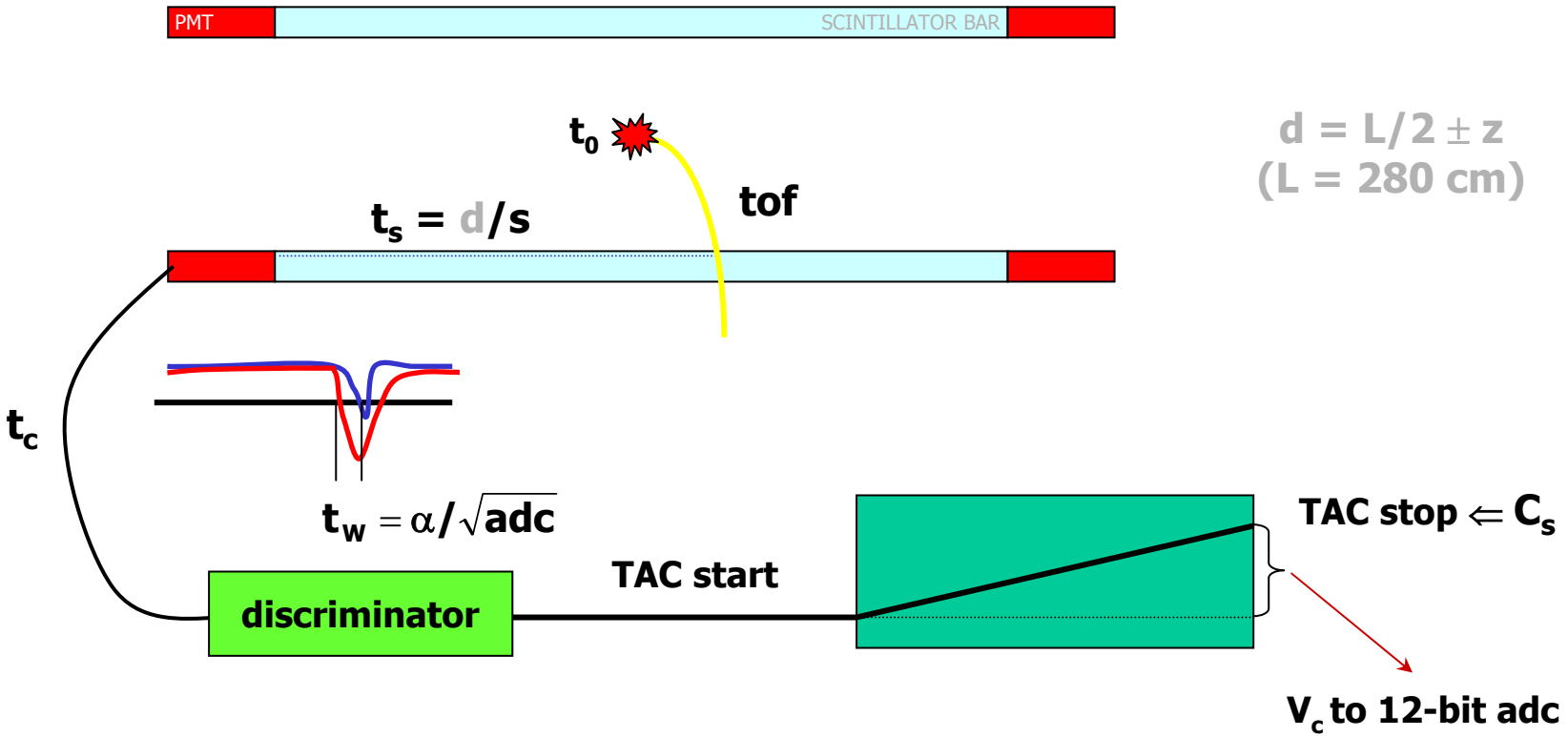
- Hamamatsu R7761
- Fine mesh, 19 stage
- Gain reduction 500 @ B=1.4 T
- Small TTS: 250-400ps

TOF Milestones

- Test run (5% "full scale") in 1995
- Approved in January 1999
- Fully installed in August 2000
- Electronics in August 2001
- Stable data taking from October 2001

TOF technique

Objective: flight time of the particle from collision to TOF detector



$$TDC = C_S - (t_0 + tof + t_s + t_c + t_w)$$

Calibrations (I)

- ADC calibration
  - Pedestals measurement and linearity check
- Time-to-Amplitude Converter (TAC) calibration
  - Digital delay generator to study non-linear response

on-line

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off-line

- Time walk effect
  - Due to dependence of discriminator time on pulse height (~2 ns)
- Speed of signal propagation in bars
  - Times depend on z position of hit along the bar (~20 ns)
- Channel-to-Channel time offset
  - Includes cable lengths and clock signals (~1 ns)
- Residual correction in z position along the bar
  - Residual dependence of time with the position (~200 ps)

Calibrations (II)

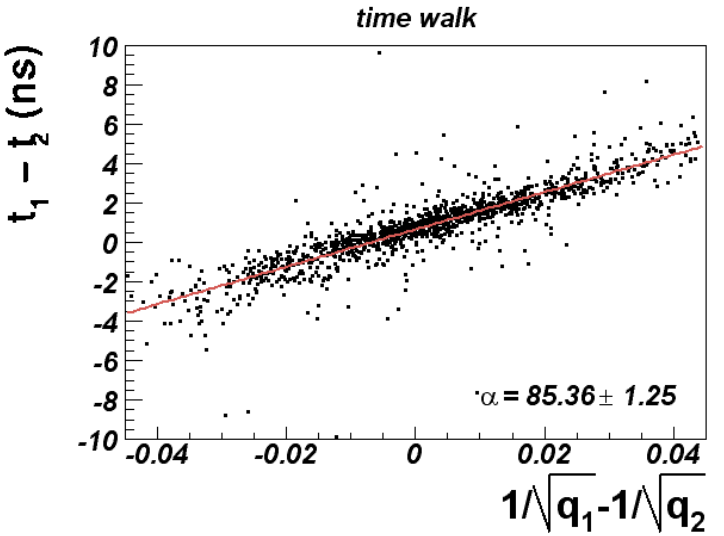
Time walk correction

Due to leading edge pick-off method

Larger pulses fire the discriminator at earlier time than smaller pulses

Effect studied with tracks passing through two adjacent bars of scintillator

$$F(Q) = \frac{-\alpha}{\sqrt{Q}}$$

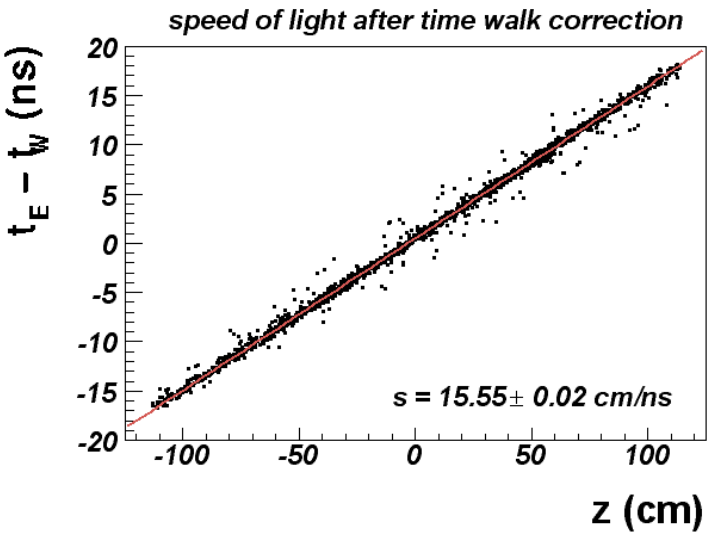


Time difference vs. z

The effective speed of light comes from the fitted slope

Time walk dependence is absorbed in the fit

$$t_E - t_W = t_E^0 - t_W^0 - [F_E(Q) - F_W(Q)] + 2z/s$$



t_0 calculation

The CDF TOF detector has unique conditions

Long bunches $\sigma_z \sim 30$ cm $\Rightarrow \Delta t_0 = \sigma_z/c \sim 1$ ns >> σ_{tof}

Need to calculate t_0 event by event to achieve the design resolution

Perform likelihood fit track by track

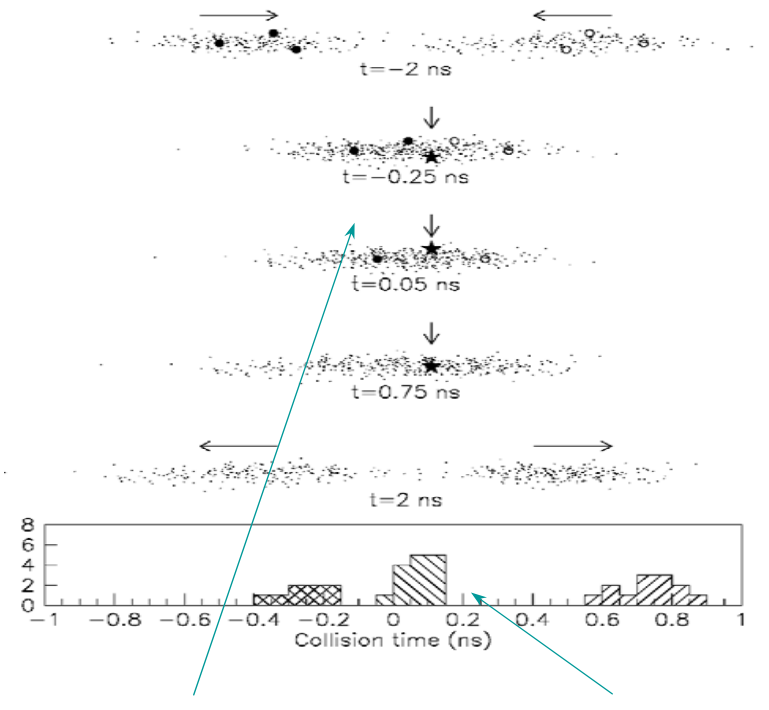
≥3 good tracks/event but the track of interest

For each track hitting TOF

$t_0^{\pi,k,p} = TDC - t_c - t_w(Q) - t_s(z) - TOF^{\pi,k,p}$

Choose π,k,p with probabilities $f_{\pi,k,p}$ ($\Sigma f_i \equiv 1$)

$$\sigma(t_0) \sim \frac{100\ ps}{\sqrt{N_{tracks}}}$$



Three $p\bar{p}$ interactions in one bunch crossing at the same z

Times of individual collisions measured with TOF detector

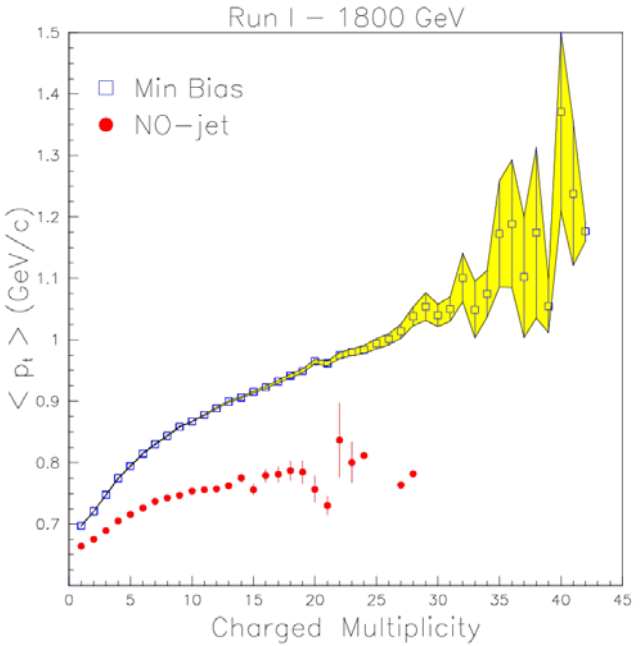
TOF triggers

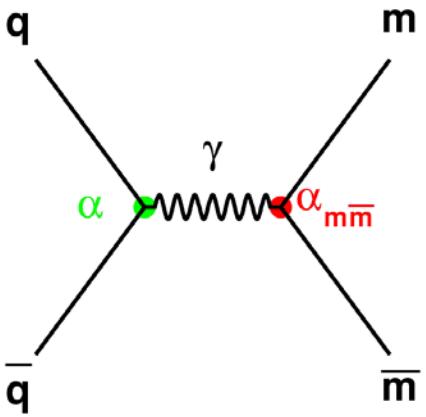
Low amplitude threshold

Minimum Ionizing Particle (MIP)

COT multiplicity > 22
14 MIPs hits in TOF (MIP > 400 ADC)

QCD physics
Studies of Minimum Bias (high multiplicity) events
Try to explain non perturbative soft interactions





High amplitude threshold

Highly Ionizing Particle (HIP)

Trigger rate is kept below ½ Hz
Data shows a linear response from zero to four MIPs

Exotic physics
Dirac Magnetic Monopole Search
Deposit large amount of energy along the way

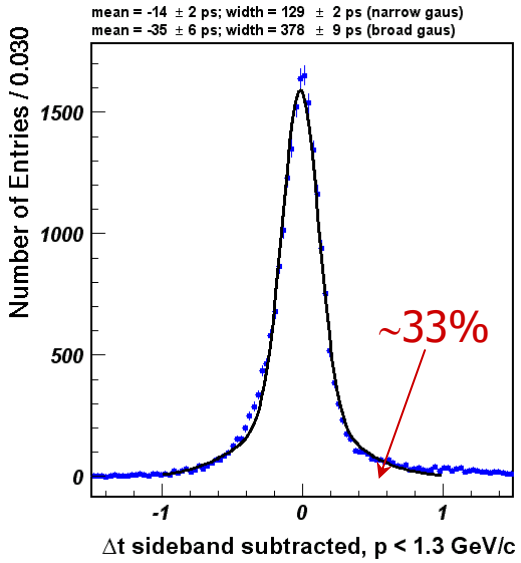
TOF resolution
(pure pion sample)

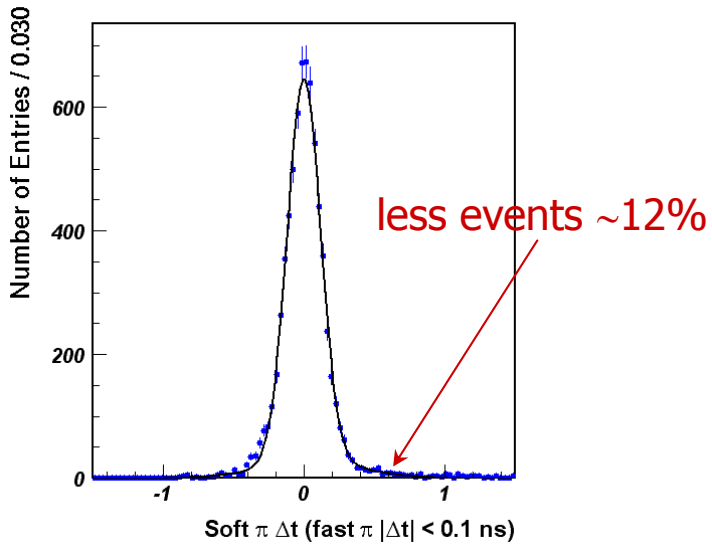
- Data (~65 pb^{-1}): two displaced tracks, $P_t > 2$ GeV/c
- Decay of interest: $D^* \rightarrow D^0\pi^{\pm} \rightarrow [K\pi]\pi^{\pm}$

soft pion

t_0 correlation between two pions
Get t_0 from fast π ($|\Delta t| < 0.1$ ns), used
to the second π

$\Delta t \equiv Tof_{measured} - Tof_{expected\ \pi}$





Narrow gaussian ⇒ 129 ± 2 ps
Broad gaussian ⇒ 378 ± 9 ps

Narrow gaussian ⇒ 118 ± 2 ps
Broad gaussian ⇒ 340 ± 22 ps

TOF resolution
(high P_t samples)

t_0 is calculated for the two highest momentum tracks assuming speed of light

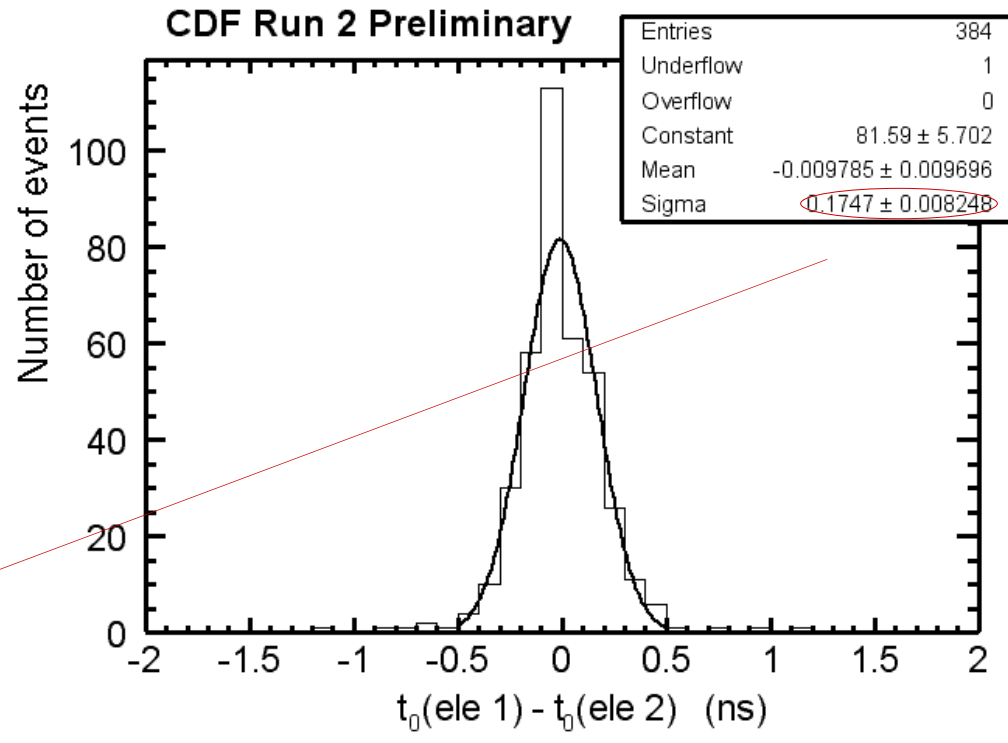
Sample, high P_t electrons

Decay of interest

$$Z^0 \rightarrow e^+e^-$$

TOF resolution

$$(175 \pm 8)/\sqrt{2} = 124 \pm 6 \text{ ps}$$



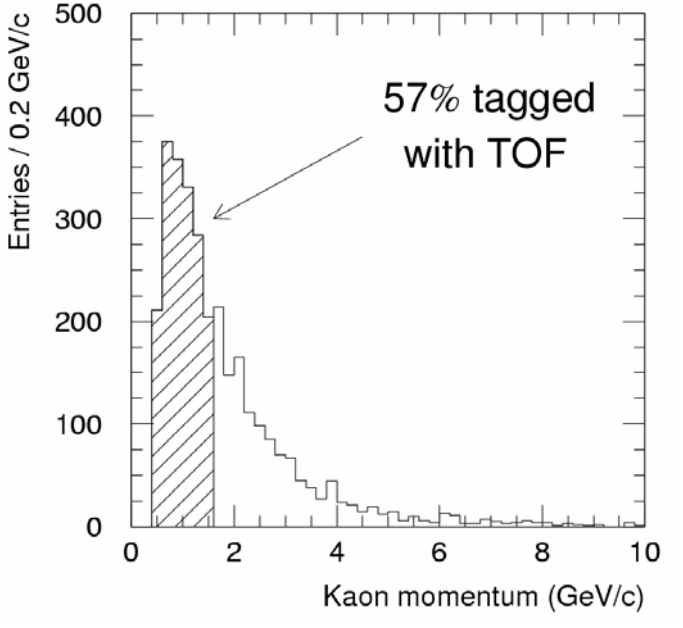
Also done with other high P_t samples:

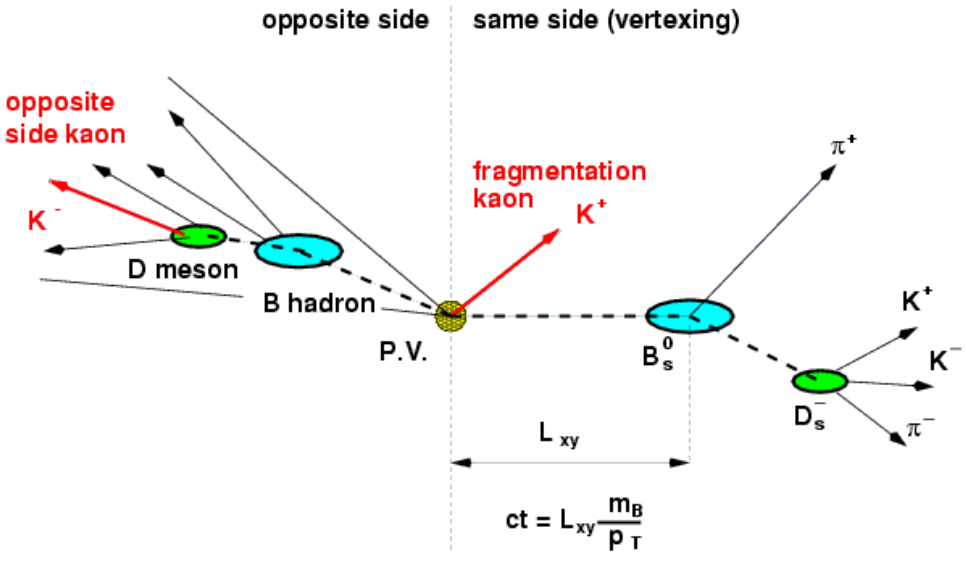
- Dijet with resolution of 123 ± 11 ps
- Multijets with resolution of 139 ± 4 ps

Physics with TOF (I)

B physics TOF designed mainly for flavor tagging

Flavor oscillation and CP asymmetry → determine the B flavor via kaon ID





Opposite side tagging:

exploits B weak decays $b \to c \to s$

($b \to K^- X$ but $\bar{b} \to K^+ X$)

Same side tagging:

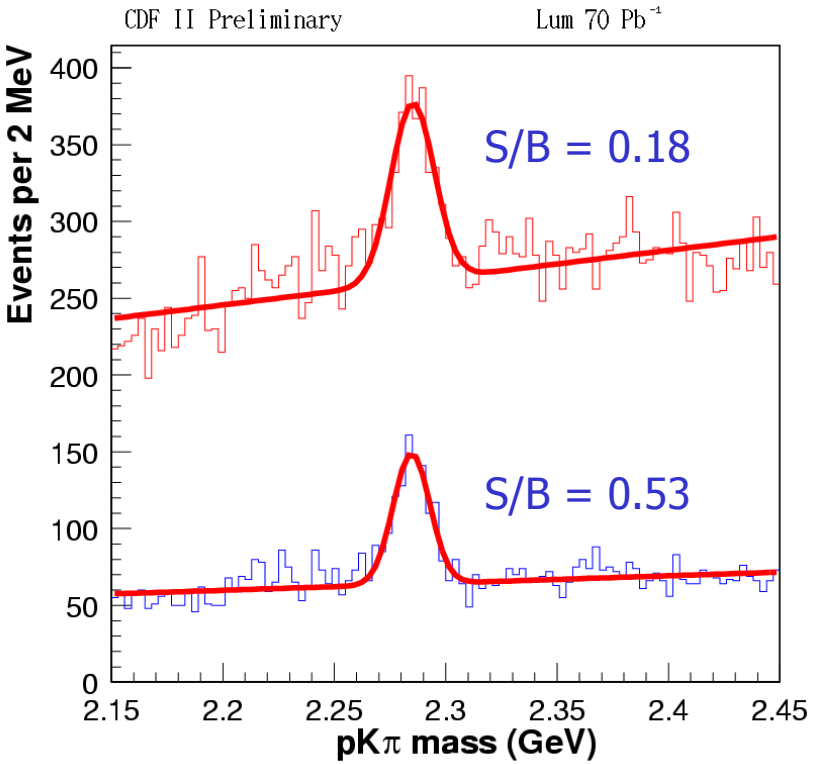
exploits correlation between b flavor and particles produced in hadronization

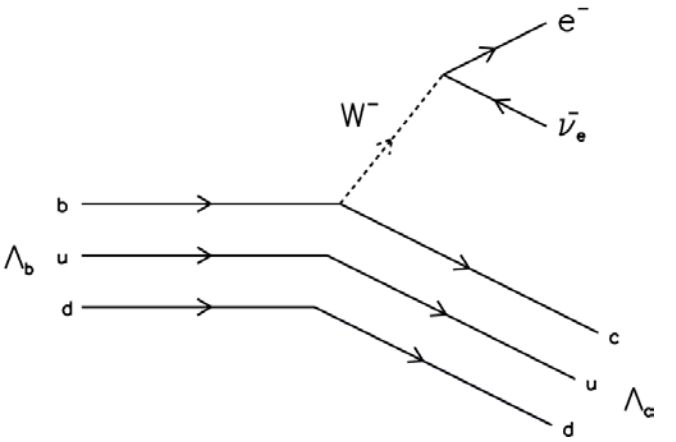
$\pi \leftrightarrow B^0$, $\pi^- \leftrightarrow \bar{B}^0$, $K^+ \leftrightarrow B^0_s$

Physics with TOF (II)

B physics $\Lambda_b \rightarrow \Lambda_c l\nu \rightarrow [pK\pi]l\nu$

TOF (and dEdx) used to identify the proton to reduce greatly backgrounds





Particle ID with pseudo likelihood ratio (signal efficiency = 64 %)

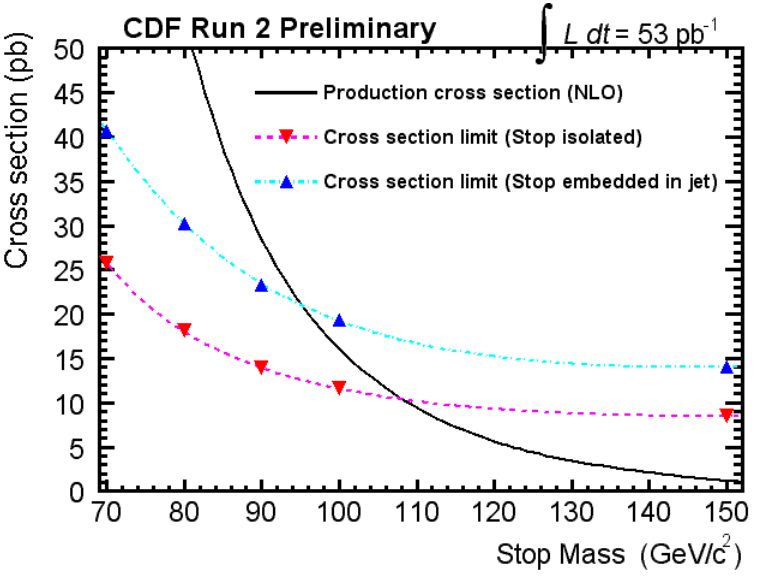
Λ_b lifetime can be measured using an unbinned likelihood fit to the proper decay lengths of the $\mu+\Lambda_c$

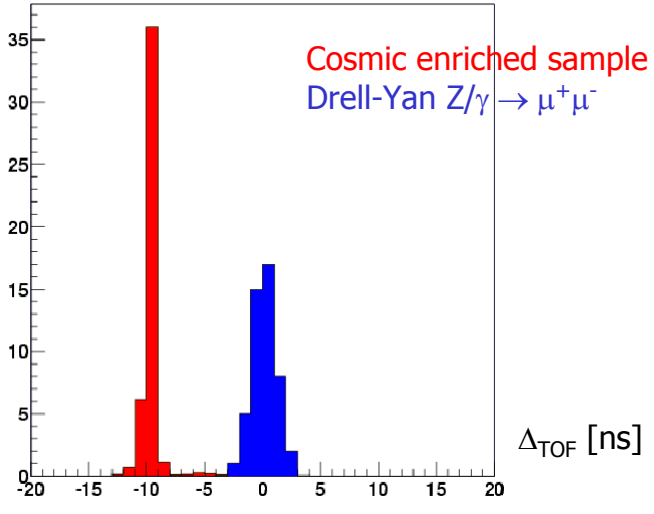
Physics with TOF (III)

Exotic physics

Massive long-lived charged particles (CHAMPS)

- High P_t muon events
- Large energy loss
- Isolated candidate tracks
- Search for slow particles





Cosmic rays rejection

High Pt muon pairs

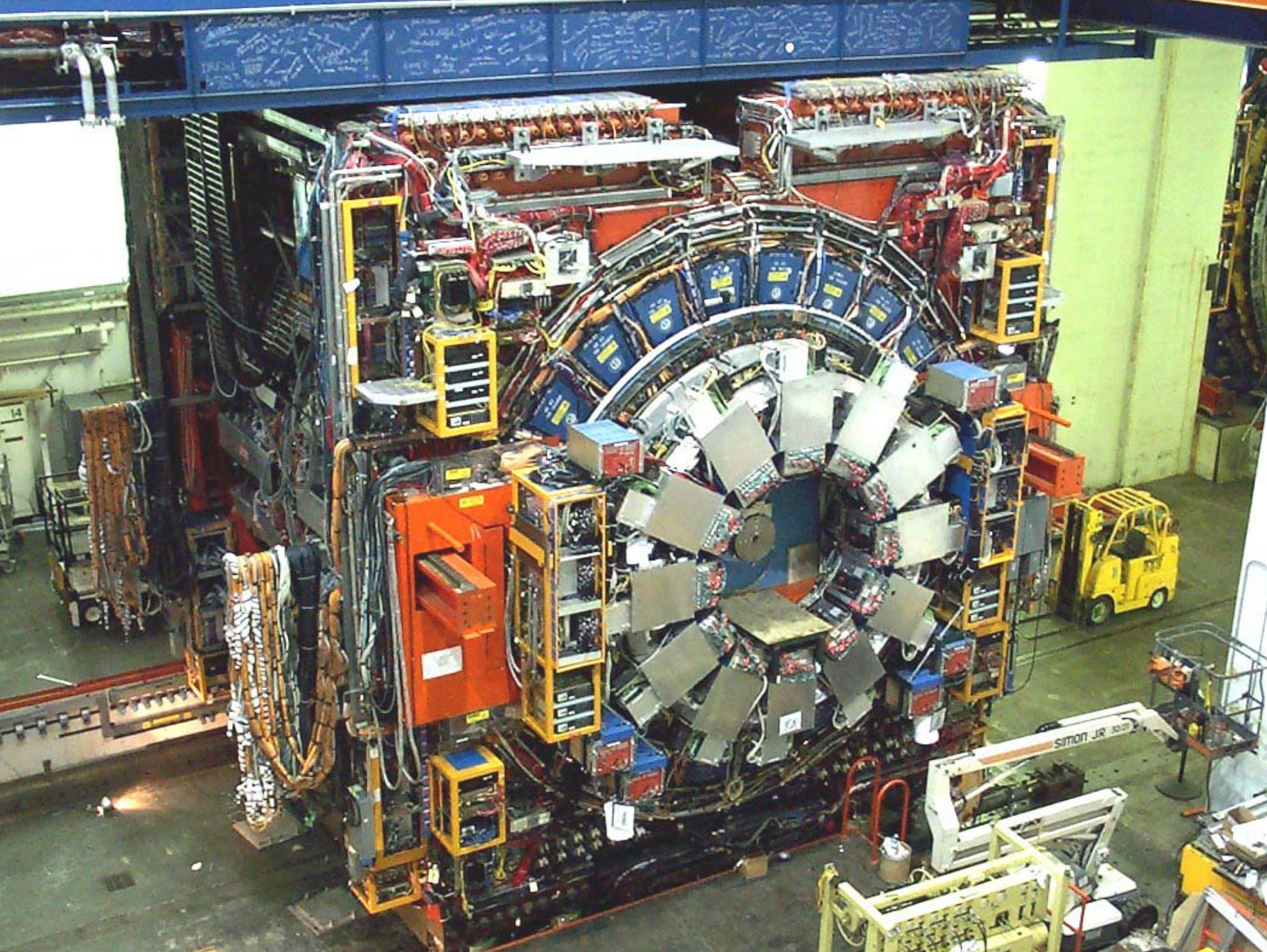
High P_t physics

Significant background to Electroweak & Exotic physics

Conclusions

- TOF fully operational and reliably working since October 2001
- Resolution sensitive to t_0 calculation, depends on the analysis
- Trigger hardware (MIP and HIP) installed and working
- Being used for several physics analysis
- Flavor Tagging results soon

Backup slides


SIMON JR

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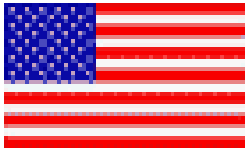
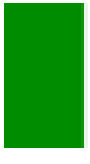
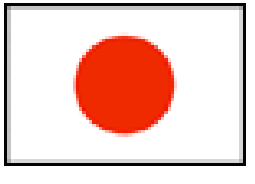
U. Tsukuba: H. Kaneko, A. Kazama, S. Kim, K. Sato, F. Ukegawa

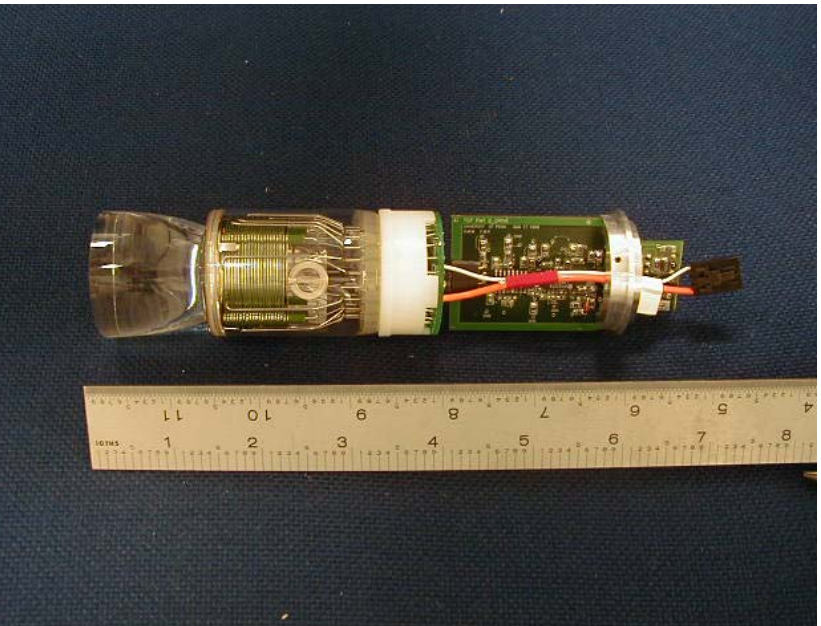



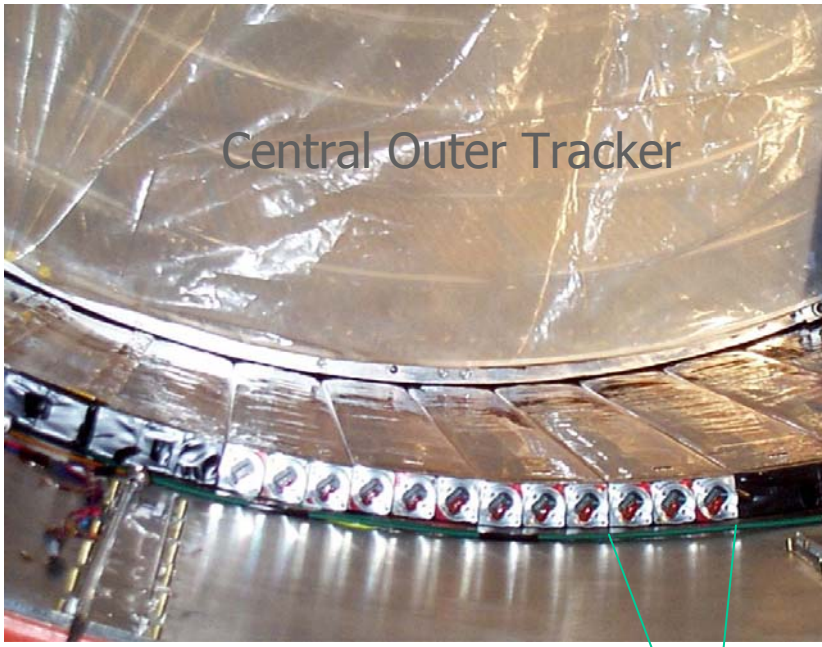




Mechanics and phototubes

- Custom-made Hamamatsu R7766
  - 19 dynode (high gain)
  - Fine mesh (increased tolerance @ 1.4 T)
  - Small size 1.5 x 2.5 inches
  - Operated with a positive HV up to 2500 V
  - Gain reduction factor at B = 1.4 T ~ 500

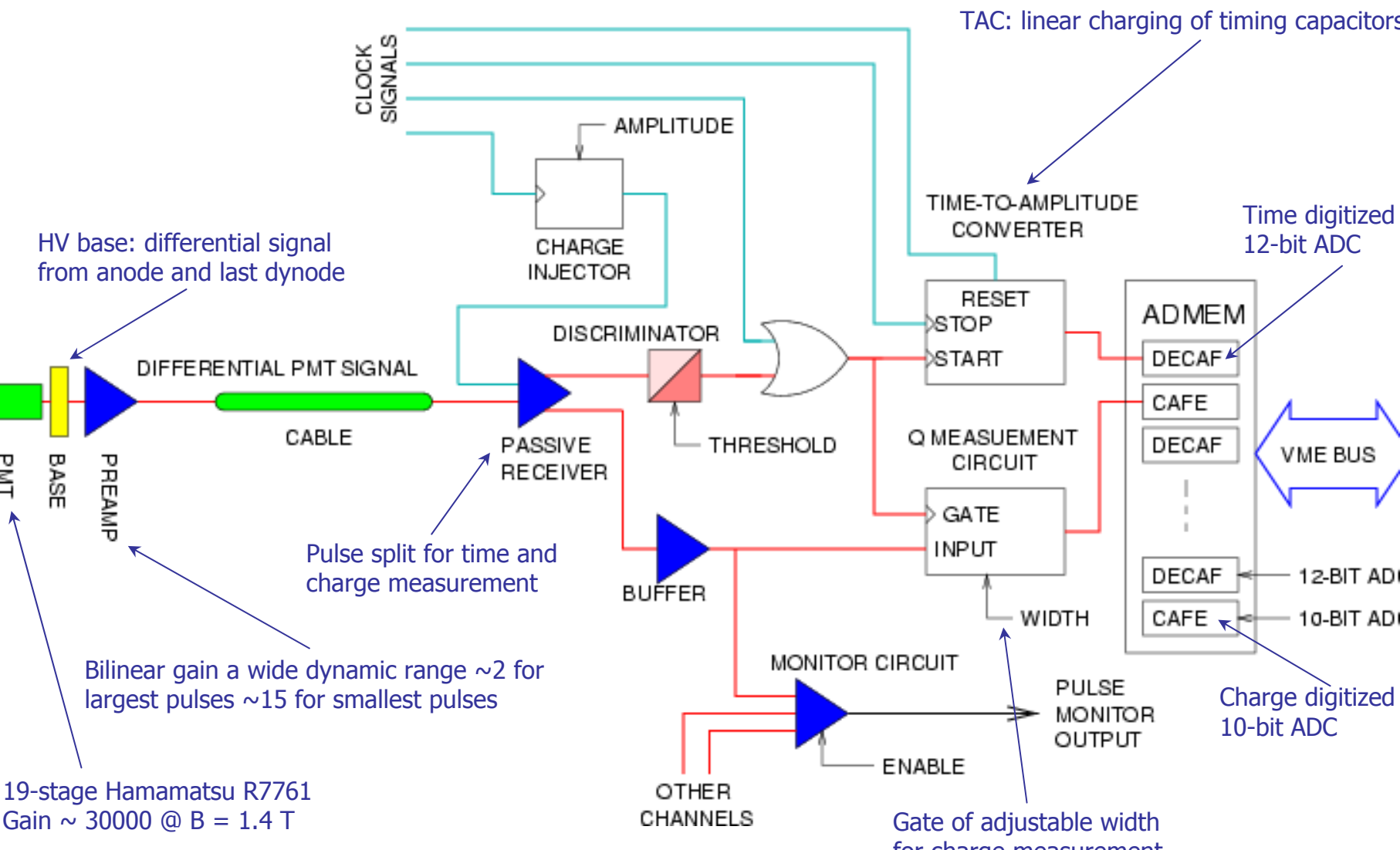




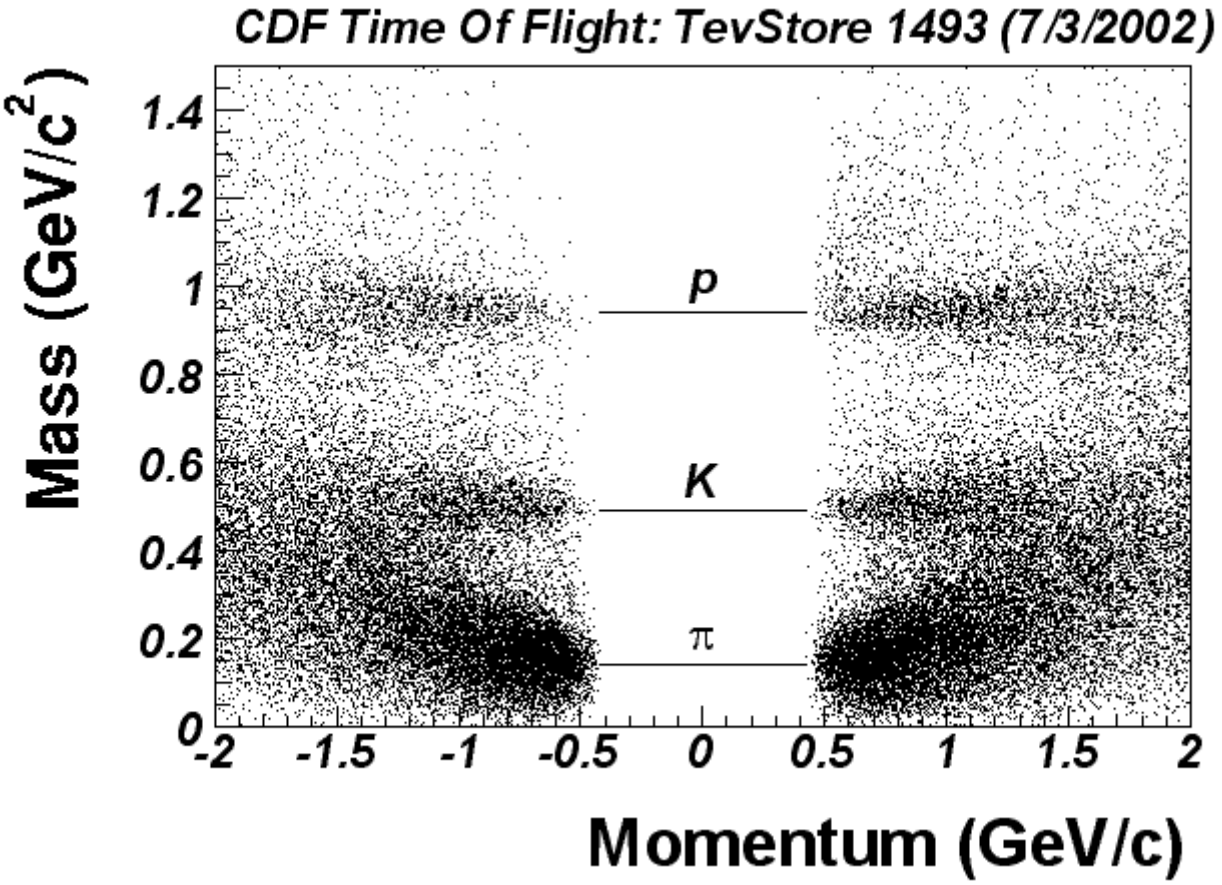
- Scintillators assembled in 72 triplets
- PMT in Alu holders
- Tight radial clearance (few mm)

TOF signal path

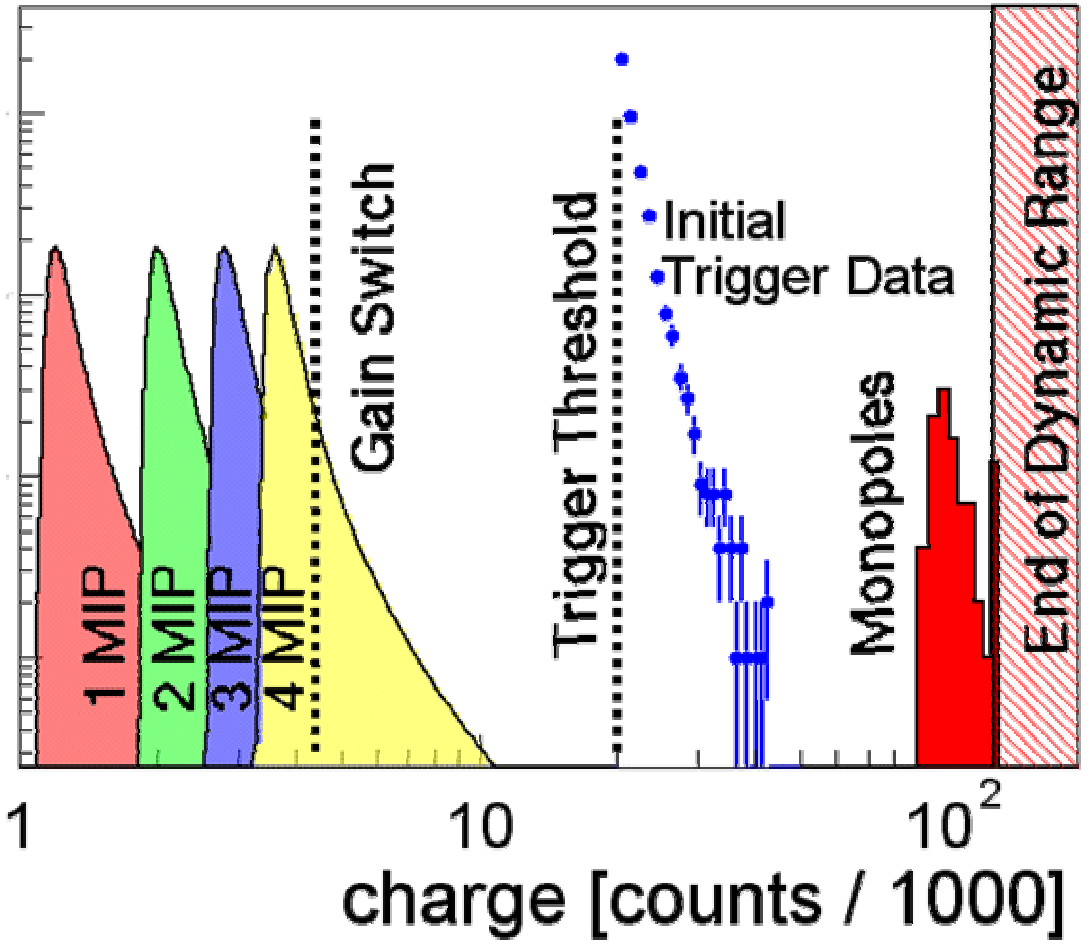
Electronics contribution to overall resolution < 25 ps



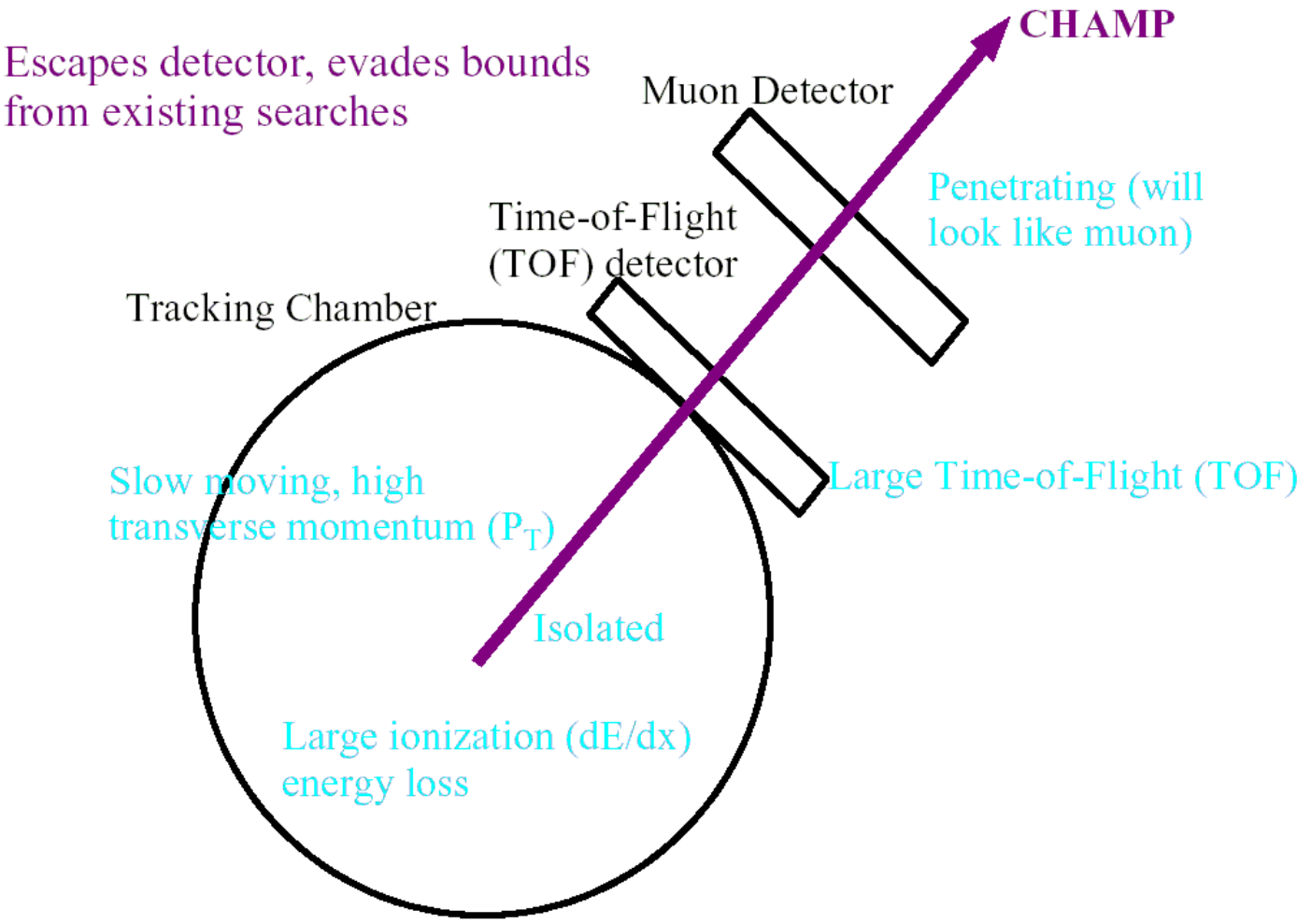
Mass separation



Monopoles


1 MIP
2 MIP
3 MIP
4 MIP
Gain Switch
Trigger Threshold
Initial
Trigger Data
Monopoles
End of Dynamic Range
1
10
10^2
charge [counts / 1000]

CHAMPS


CHAMP
Escapes detector, evades bounds from existing searches
Muon Detector
Penetrating (will look like muon)
Time-of-Flight (TOF) detector
Tracking Chamber
Large Time-of-Flight (TOF)
Slow moving, high transverse momentum (P_T)
Isolated
Large ionization (dE/dx) energy loss